Technical Report * 3

From The Crawford Hill VHF Club
Date: (1970), slightly modified Oct. 1986

Subjects: **<u>System Consideration for the E M E Path</u>**

Of all the radio propagation paths used by radio amateurs, few can be accurately predicted in terms of path loss and dependability. In the VHF-UHF spectrum, only the line-of-sight path which includes the active and passive (EME) satellite paths, can be reliably predicted since most of the path is in free-space. For the Moon as a passive satellite, the amount of reflection from the Moon has been adequately documented, and the use of high-gain antennas virtually eliminates ground reflection problems on the EME path.

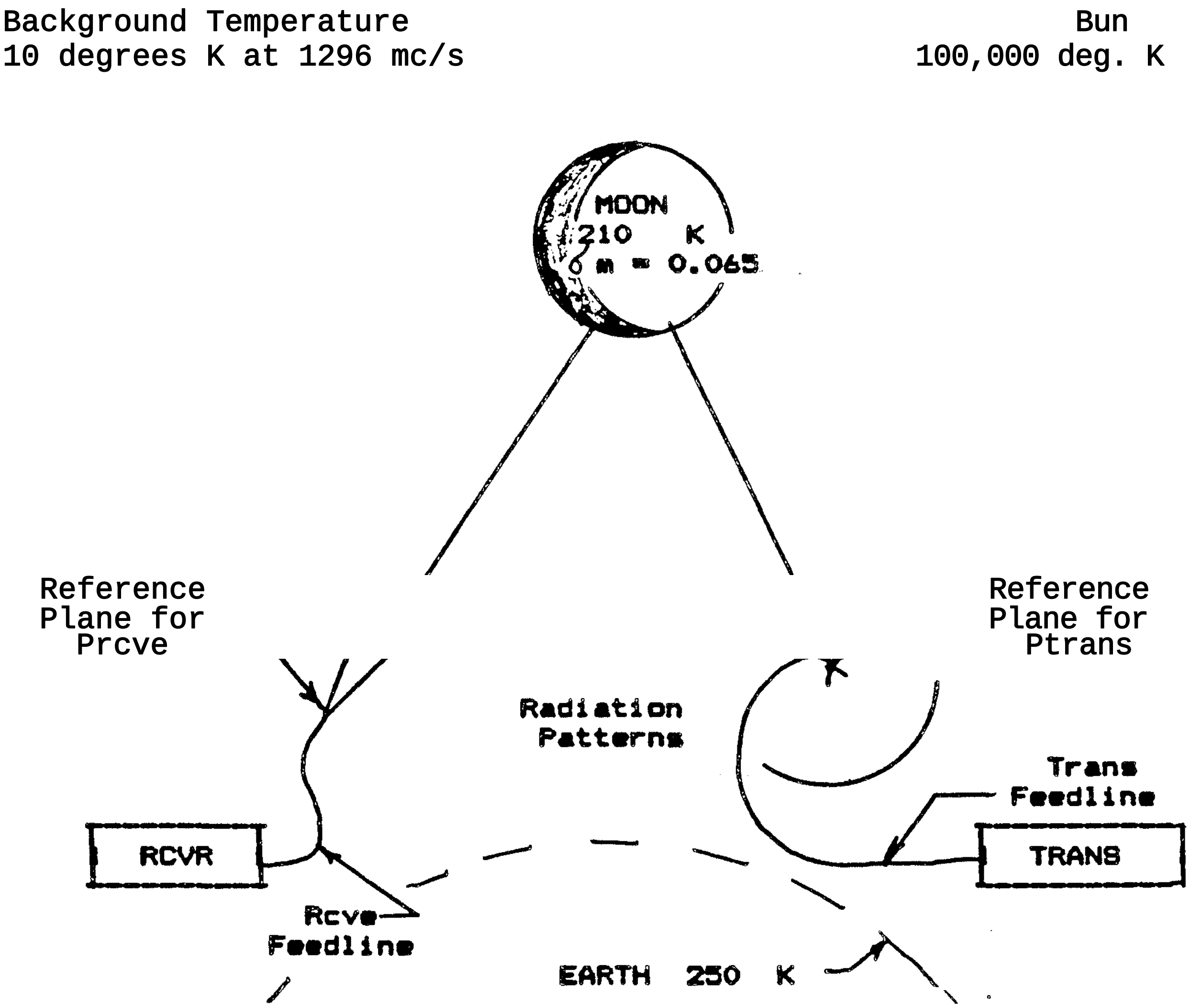
By contrast, all point-to-point VHF-UHF Earth surface paths commonly used by amateurs make use of some freak of nature such as sporadic-E, ducting, temperature inversions and fronts, Aurora, meteor trail scattering, etc., which are unpredictable, sporadic and not at all useful for 'real time' amateur communication. Even the so called line-of-sight paths generally involve ground reflections which though constant for a given situation, are difficult to predict.

The EME path is particularly noteworthy for UHF because of the accuracy with which path loss calculations can be made and for its dependability. These factors permit the EME path to be used for reliable DX communication and as a means of antenna and system evaluation.
The great distance to the Moon (high path loss) and the Moon's poor reflective properties make this propagation path appeal to those interested in advanced work on receivers, transmitters and antennas for the UHF spectrum. Indeed, because of the great path loss involved and the license power limitations, every part of the station facilities must be optimized to achieve success. The first major step in individual station success occurs when reception of echoes is achieved. The echo property of the EME path is unlike any other propagation .path, except cross-band active satellite paths, since achievement of echoes means that your station is now capable of communicating with any other station that can receive echoes.

The EME path therefore provides a challenge for the amateur who wishes to upgrade his technical ability and explore new horizons in DX communication.
In this report, the total system aspect of EME transmission will be considered briefly. The system includes both the transmitting and receiving equipment, as well as the EME (Earth-Moon-Earth) path. Little will be indicated about the components of the system except their characteristics as related to the system. For instance, the single important system characteristic of the transmitter is its power output; it is assumed the frequency stability, And r-f purity, d-c input limitations, etc., are all

satisfactory and meet license requirements.
No modulation is considered, and the system operates CW with the final detector being the human ear.
In presenting this material, a number of objectives are indicated; a better understanding of the total system, to bring into focus those characteristics of a system which are most important, to indicate where trade-offs can be made in an individual system, and to provide all the relations necessary for complete system evaluation on a mathematical basis.

THE EME SYSTEM



To illustrate the EME system, a one-way path is chosen and shown by the above drawing in which a paraboloidal reflector type antenna is shown for transmitting and a horn type antenna is

these calculations is to show that if all components of the system can be accurately characterized, then an accurate determination of signal-to-noise ratio at the receiving

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detector can be made. And this in turn determines whether of not the system is adequate for EME communication.

The procedure employed here to determine S/N is: (a) compute the received power level, Ps, at the receiving antenna terminals given the antenna gains, transmitting power and path loss, (b) next a system noise power, Pn, referred to the receiving antenna terminals is computed based on the overall system operating temperature, Toys, and the receiver effective noise bandwidth, and finally (c) form the ratio of Ps-to-Pn„ which is the signalto--noise ratio. It should be mentioned here that when measuring the output of a receiver the ratio of (8+N)/N is actually measured. (A convenient curve relating 8/N to (8+N)/N can be found in Tech. Report * 11.)

In the calculations to follow, the receiving system effective noise bandwidth employed will be 50 cycles per second (Hz). This is based on human 'ear' detection and does <u>not</u> imply that the receiver have a 50 cps filter included. It has been adquately demonstrated that the receiver bandwidth can be as great as 3 kc/s without impairing the ability of the ear-brain filter-detector from detecting a single CW signal in noise. It has also been adequately demonstrated that a signal-to-noise ratio of unity is extremely marginal for the ear-brain system to detect. For reliable CW communication, a minimum 8/N of + 6 dB is desirable (ear-brain 50 cps in a 3 kc/s band of noise). The reason for selecting the ear-brain system as the final detector is that the ultimate objective of the EME program is 'real-time' communications. While more sophisticated detection processes can be employed to dig the signal out of the noise, the information rate will suffer (slower keying speed).

<u>gvstem Noise</u>

The system noise power <u>referred to the receivino antenna terminals</u> is

$$Pn = k\ Tsys\ B \qquad (2)$$

Where k = 1.38 x 10E-23 watts/cycle-°K, Boltzmann's constant,= 50 cycles per second (Hz), the receiving system effective noise bandwidth,

and, Tsys is the system operating temperature in degrees Kelvin.

shown for receiving. The components of the system are characterized as follows:

Po is the transmitter power output,
Lt is the transmitting feedline loss,
Gt is the effective gain of the transmitting antenna,
Gr is the effective gain of the receiving antenna,
Ta is the receiving antenna temperature in degrees Kelvin,
Lr is the receiving feedline loss,
Tl is the temperature of the receiving feedline in $^{\circ}$ K,
and Tr is the receiver input temperature in $^{\circ}$ K.

In addition, the EME path may be characterized by:

R is the distance between the center of the Moon and the center of the Earth (238,636 s. miles +/- 1 db),

dm is the diameter of the Moon (scattering object) 2160 s. miles,

λ is the free space wavelength for the desired operating frequency, in statute miles, to be consistent with R and dm units, and

δ_M is the reflection coefficient of the Moon (0.065 in the VHF-UHF portion of the spectrum).

Using the antenna terminals as convenient reference points for calculating power levels, the total path loss between <u>antenna terminals</u> is

$$\text{Path Loss} = \frac{\text{Prcve}}{\text{Ptrans}} = \text{Gt Gr} \left| \frac{dm^2 \lambda^2 \delta_m}{(16\pi)^2 \; R^4} \right| . \qquad (1)$$

The bracketed term is the 'free space' path loss between antenna terminals with Gt = Gr = 1 (isotropic antennas), and is tabulated below for convenience,

Frequency in mc/s(mHz)	Free Space Path Loss +/- 1dB between isotropic antennas
50	- 242.9 dB
144	- 252.1 dB
432	- 261.6 dB
1296	- 271.1 dB
2300	- 275.5 dB

The +/- 1 dB variation is to account for variations in the range R, since the Moon orbit is not exactly circular. At 1296 mc/s where atmospheric and ionospheric attenuation is almost always negligible, the free space path loss of - 271.1 dB is quite accurate for all cases where the antenna is uneffected by the presence of the Earth (high elevation angle). The purpose of

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and, Tsys is the system operating temperature in degrees Kelvin.

Tsys includes the antenna noise temperature as well as the overall receiver noise and any interconnecting line losses between antenna and receiver.

$$Tsys\ Ta + (Lr - 1)\ T1 + Lr\ Tr \qquad (3)$$

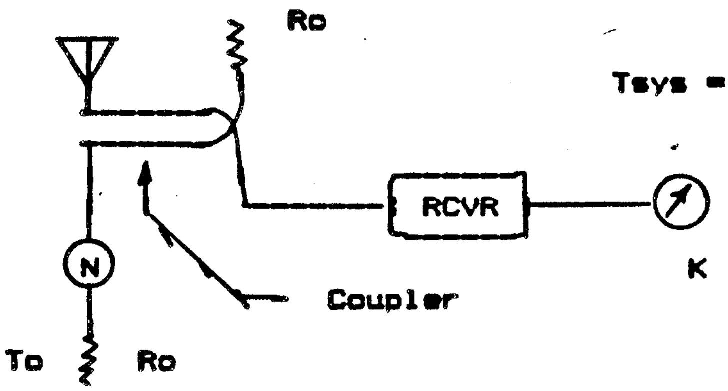
where the various terms have been defined on page 2. Lr, the receiving feedline loss is • pure number greater than 1 in this context.For a loss of 1 dB, Lr = 1.26. Loss in decibels (dB) =
10 log Lr.
Tsys therefore acounts for all the noise in the system referred to the receiving antenna terminals rather than the receiver front end, arbitrarily and for convenience.
Tr, the receiver overall noise temperature, preamp plus receiver system, is related to noise factor, NF, by

$$Tr = (NF - 1)\ 290°K \text{ (IEEE definition)}$$

A good estimate of overall receiver noise factor can be made from just knowledge of preamplifier NF and gain, and post amplifier NF. This two stage amplifier has a combined NF of

$$NFsys = NF\ preamp + (NFpost\ amp - 1)/G\ preamp.$$

Ta, the antenna noise temperature is a measure of the noise power which the antenna picks up from sources such as the warm Earth or noisy regions of the Galaxy and should not include man-made noises. Ta varies with the physical positioning of the antenna and is usually a difficult quantity to determine (see Tech. Reports * 5 and M 11).
Fortunately, Tsys may be measured directly by introducing a calibrated noise source into the feedline at the antenna terminals by means of • weakly coupled directional coupler, with coupling factor less than - 20 dB.



$$Tsys = \frac{C}{K - 1}(Tn - K\ To)$$

Where C is the coupling coefficient of the directional coupler,
TN is the "ON" temperature of the calibrated noise source,
To is the temperature of the noise source termination Ro, and K is the ratio of the receiver output noise power for conditions of noise source "ON" to "OFF". This scheme is very

Sample of System Calculations for 1296 mc/s

It is convenient and customary to compute power levels in milliwatts (mw.), and also relative to one milliwatt when using decibels. By definition then, a power level of one milliwatt is referred to as 0 dBm.

To illustrate a system calculation, assume that all the necessary numerical characteristics of the system are known with some degree of accuracy. The ultimate question is, can a signal be detected on a one-way transmission basis using audible detection methods (your ears). Lets

Po = 250 watts or + 54 dBm (transmitter output power) Lt = 1.26 or 1 dB of feedline loss for transmitting

Gt + 32 dB (transmitting antenna gain - this is equivalent to a fully illuminated 10 foot circular aperture) Gr + 32 dB (receiving antenna gain)

Ta R 20° K (receiving antenna temperature - typical of a good horn antenna aimed near the zenith at 1296 mc/s)

Lr = 1.26 or 1 dB receiving feeline loss at a temperature of 290 K (room temperature)

Tr gm 75.4 K, equivalent to a 1 dB preamp-post amp temperature. Tr = (1.26 - 1) 290° K

Calculate the system operating temperature using equation (3):

Tsys ma (20 + (1.26 -1) 290 + 1.26 (75.4)) degrees Kelvin

am 20 + 75.4 + 95= 190.4° K

Calculate the receiving system noise power, Pn, referred to the receiving antenna terminals using equation (2). A more convenient form of this equation is

$$Pn = k\ Tsys\ B \qquad (k\ To)\ \frac{Tsys}{To}\ B, \qquad \text{where } To = 290^{o}\ K.$$

In decibel form (k To) computes to be - 174 dBm/cycle, and

$$P_n \text{ (in dBm)} = -174 \text{ dBn/cycle} + 10 \log_{10} \left(\frac{T_{sys}}{T_o} \right) + 10 \log_{10} (B)$$

For B = 50 cycles (Hz) and Tsys = 190.4 K,

$$P_n \text{ (in dBm)} = -174 + 10 \log (0.656) + 10 \log (50) =$$

$$- 174 - 1.82 + 17$$

$$= -158.8 \text{ dBm}$$

Now consider the received signal power level in dBm
Ps (in dBm) = + 54 dbm - 1 db (feedline loss) + 64 dB (antenna gain) - 271 db (path loss)

Ps (in dBm) - 154

Finally, the S/N ratio

$$\frac{P_s}{P_n} \text{ (in decibels)} = P_s \text{ (dBm)} \quad P_n \text{ (dBm)}$$

$$= -154 \text{ dBm} - (- 158.8 \text{ dBm})$$

$$= + 4.8 \text{ dB !}$$

Since the S/N is only 4.8 dB, this system must be considered to be marginal for communication, but detectable signals should be obtained.

Let us now remove the feedline losses for both receiving and transmitting, and recompute the S/N. This situation would occur perhaps in a station where a common feedline would be used between feed antenna and the equipment, and the signal were of echoes. In this case

$$T_{sys} = (20 + 75.4) \quad K$$
$$= 95.4 \text{ K}$$

$$P_n(\text{dBm}) = (- 174 - 4.8 + 17) \text{ dbm} =$$
$$- 161.8 \text{ dBm}$$

$$P_s(\text{dBm}) = (+54 + 64 - 271) \text{ dBm} =$$
$$- 153 \text{ dBm}$$

and,

$$S/N \text{ (dB)} = -153 - (- 161.8) \text{ dB}$$
$$= + 8.8 \text{ dB "}$$

An increase of 4.0 dB in S/N by removing a 1 dB (common to both Tx and Rx) lossy feedline. This surprising improvement was only

possible because both the receiver and antenna temperature were low. This also illustrates the sensitivity of losses in the system, especially between the antenna and preamplifier.

It is interesting and obvious to note that nowhere in the system S/N calculations does the transmitting antenna temperature appear. This leads to the obvious conclusion that for transmitting, the antenna aught to have maximum gain. regardless of other factors. However, for receiving, the antenna temperature is an important consideration as well as its gain. In general. 1 + the receiver temperature is known and receiver feedline losses are very small, then an antenna temperature comparable or slightly smaller than the receiver temperature is desirable.

An antenna quality factor for maximizing signal sensitivity is the' ratio Ge++ective/Tantenna. The higher G/T. the better the antenna will perform in receiving signals. especially weak EME signals. This paradox in antenna requirements can be accomodated in the case of the parabolic reflector antenna by providing a feed which has adjustable illumination properties.

Since the maximum transmitter power is fixed by license regulations, it is highly desirable to take adantage of the low background temperature of the Universe at 1296 mc/s and higher, and employ receiving antennas with low temperature and the best state-of-the-art preamplifiers to improve S/N.

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